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THE MEASUREMENT OF NAVAL FACILITIES
MAINTENANCE EFFECTIVENESS

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[redacted]

Submitted in partial fulfillment of
the requirements for the degree of

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IN
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ABSTRACT

Implementation of recommendations of the Review of Management of the Department of the Navy and recent trends in Department of Defense policies require that the Bureau of Yards and Docks maintain a continuing effort to maximize the effectiveness of facilities maintenance resources. A means of measuring maintenance effectiveness would greatly assist in determining the capabilities of present systems and in spotting areas where greater improvement is needed. The concept of effectiveness is explained, and basic conceptual steps to be taken in its attainment outlined. Recent maintenance developments and operations in private industry and public agencies within the State of California are summarized. A proposal is made for use of military worth concepts in determining relative priority of work requests at the local level, including a report of two introductory experiments to test the theoretical application recommended. An "ideal" measurement system is outlined, with major measurement problems discussed and recommendations for further study listed.

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CHAPTER I

BACKGROUND

IMPLEMENTATION OF DILLON REPORT RECOMMENDATIONS.

The Bureau of Yards and Docks has historically been a leader in attempts to improve the efficiency and effectiveness of facility maintenance programs. It has long been recognized that budgets for maintenance of Naval facilities are severely limited, and that the utmost in actual effective maintenance effort must be realized from each maintenance dollar expended.

Of particular importance in recent months, however, is the increased facilities maintenance responsibility assigned to the Bureau of Yards and Docks as a result of the approval of recommendations 76 and 77 of the Review of the Management of the Department of the Navy - the "Dillon Report." Recommendation 76 of that report provides for assigning to the Chief of the Bureau of Yards and Docks the responsibility for maintenance of buildings, grounds and structures and the operation of utilities, except for the Marine Corps.[1] Recommendation 77 would assign to the Bureau of Yards and Docks the responsibility to devise and implement a management-oriented budget and information system for public works management.[2] The budget and information system would integrate present data-collection systems, improving them as necessary to increase the

[1]United States Department of the Navy, Review of Management of the Navy, Vol. I (Washington: Department of the Navy, 15 December 1962), p. 127.

[2]Ibid., pp. 129-30.

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effectiveness of the budgeting and appraisal functions. The Secretary of the Navy has generally approved the recommendations of the Review of Management of the Department of the Navy and has specifically approved the concept of a single manager for maintenance of facilities.[3]

Implementation of these recommendations in the fullest sense will require the Bureau of Yards and Docks, through their Field Engineering Offices, to be able to review and analyze the maintenance activities of the Navy to obtain some indication of each activity's maintenance effectiveness. A successful reviewing tool would greatly assist the Bureau of Yards and Docks in knowing where best to apply the limited maintenance funds which will be available. Without a means of measuring maintenance effectiveness it would be difficult to avoid major errors in the allocation of maintenance resources. Such an evaluation tool must also be capable of working effectively across Management Bureau lines of interest as these may apply to each of the individual activities being evaluated. The system must also be responsive to the needs of the new Fleet Activities Command, which will influence the facilities management area in some, as yet not precisely defined, manner. The concept of a single-manager for facilities maintenance is actually in conflict with the concept of a shore-based Fleet Activities Commander who is expected to exercise central control

[3] SecNav letter of 9 February 1963 to all ships and stations, subj: Report on "Review of Management of the Department of the Navy".

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over those elements in direct support of fleet forces.[4] This conflict may present a major challenge to any system of measuring maintenance effectiveness. Any measurement tool used must be capable of satisfying extensive inter-agency and inter-office criticism of resource allocations.

Department of Defense trends. Probably the keynote of the current Department of Defense administration has been the increased use of economic analysis methods in consideration of major policy decisions. The TFX aircraft contractor selection and decision to use conventional propulsion in the Navy's next aircraft carrier are well known examples of cases where the results of the Department of Defense analysis were not favorable to the stated desires of the Navy. The Navy was not able to present its case so as to result in a favorable "cost effectiveness" analysis.

The tendency of the Department of Defense to centralize common support services under a single office, either within a single service, or within a new central Department of Defense agency, must also be noted. These changes are to be encouraged where savings in critical resources or improvements in operation are to be gained thereby, but must be resisted where the increased centralization will add little or nothing to improvement in the end product. In many instances, decentralization of authority and control may be more effective in solution

[4]United States Department of the Navy, Review of Management of the Department of the Navy, Vol. II, Study 6 of 7 Studies, Facilities Management Study, Vol. I (Washington: Department of the Navy, 26 October, 1962), p. 9

of a problem than increased centralization. Decisions of this nature must be based on a thorough knowledge of the current situation, and the best possible rational estimate of the ramifications of the proposed change. Only in this way can the advanced logic of economic analysis be meaningful.

If the effectiveness of the Navy's controlled maintenance program cannot be rationally measured, then the program will be that much more difficult to defend if criticized.

The problem. The Bureau of Yards and Docks may be expected to be under increasing pressure to increase the effectiveness of the Navy's facilities maintenance program. In the immediate future, a means must be found for controlling and standardizing facility maintenance operations throughout the Navy under the concepts of the Dillon Report. Proper "feedback," measuring the effectiveness of the maintenance program at individual activities, and on a regional and Navy-wide basis, must be developed.

In looking to the future, it may well be that the implementation of recommendation 76 is only one step on the way to consideration of eventual consolidation of all Department of Defense facilities maintenance responsibilities into one office. In any "cost effectiveness" analysis of the wisdom of such a future change, the Bureau of Yards and Docks must be able to support in logical fashion with rational numerical data the advantages of the position in this matter that it desires to support.

Even if these changes were not to develop, the Bureau of Yards and Docks, as the technical director of the facilities maintenance program, must continuously evaluate and improve the effectiveness of the Navy's maintenance program, striving to extract the maximum maintenance value from each maintenance dollar expended. Project THRIFT is just one example of the frequent pressures placed upon the Navy (and all services) to squeeze more and more military value out of each taxpayer's input dollar.[5]

One major key to solving a problem is being able to measure its status. By being able to measure temperature, one can easily detect when the room or office temperature is either too high or too low in relation to a desired standard. Action may then be taken to change the existing temperature so as to conform to the standard. One of the basic needs of the facilities maintenance program is to have a "thermometer" which will measure the effectiveness of the program. The problem, then which this study is concerned with is the following:

WHAT IS MEANT BY MAINTENANCE EFFECTIVENESS,

AND HOW MAY IT BE MEASURED?

The successful solution of this problem would be of great benefit in improving the maintenance program. Activities with poor effectiveness could be determined and appropriate funding or consultive assistance given. It would be easier to identify those activities which have

[5]Superintendent, U. S. Naval Postgraduate School memorandum of 15 January 1964, forwarding a reproduction of SECNAV message of 11 January.

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inordinate maintenance resources available to them, and provide more rational criteria for diverting maintenance funds to activities where the maintenance return per dollar would be greater. The maintenance level of similar types of installations within the Navy could be more standardized, with a resultant maximization of maintenance benefit Navy-wide. The measurement device could provide important justification data in attempts to obtain additional maintenance funds and in competing with more glamorous programs for the funds which are now available. Pros and cons of future consolidations of maintenance effort between services or agencies within the Department of Defense could be approached from a more rational position than that of mere opinion based upon service loyalty considerations and intuitive arguments.

Study limitations. The problem of maintenance effectiveness measurement is studied in this paper from a conceptual point of view, and does not include complete details as to how any one system should be established. It is thought that the first need in analyzing the problem is to develop the basic concepts of why the problem exists, what is presently being done to solve it, what concepts might prove useful for further development and some specific recommendations as to future study to further the problem solution. This much has been attempted in this study.

It is taken as a basic precept that the ultimate solution, or that which will be found to be the optimum solution, must be practical and workable at the local level, utilizing regular maintenance control

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personnel without advanced theoretical training. Theory may have to be modified for workability in some instances. In this event, the benefits of utilizing a "pure" theoretical system (even if one were to be found) would be secondary to developing a system which tells the manager in practical language the information he desires to know.

CHAPTER II

UNDERSTANDING EFFECTIVENESS

Fundamental to this study is a clear idea of what effectiveness is, and what concepts are necessary for its attainment. This involves, in turn, understanding of the concept of efficiency as distinguished from effectiveness, and the importance of the role of subjective, personal analysis, in determining effectiveness. A later portion of this chapter presents a conceptual outline of effectiveness requirements, indicating four basic steps to attain maximum maintenance effectiveness.

I. EFFICIENCY - EFFECTIVENESS - SUBJECTIVITY

Efficiency. Efficiency, as used in this study, is concerned with technological ability to achieve a certain stated output with a minimum of resource allocation. Once a decision has been made to repaint the exterior of a specific facility, it should be possible to develop a reasonably objective estimate of how long the job should take, how much material is required, and the cost of the project, given local wage rates and material costs. This estimate can be based upon the observable physical characteristics of the specific facility.

Once the job has been completed, comparison of actual costs in terms of money, labor, and material usage may be used for efficiency indicators for the painting of the facility. Comparison may be made with similar data obtained from other activities to further indicate how efficiently the job has been done, and, broadening the scope, how efficiently

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the maintenance work done at one activity has been done in comparison with how well maintenance work has been done at another activity.

The *Engineered Performance Standards* concept is a primary tool to control efficiency of maintenance tasks. Certainly the maximization of efficiency is one prerequisite to *effective* operation. Any procedure which contributes to maintenance efficiency, such as the use of Engineered Performance Standards, must be supported and utilized.

The data used in measurement of efficiency is primarily of an objective nature. The job or work performed can be described in explicit detail, particularly once it has been completed. The costs involved are merely matters of historical fact. The method used may be described in a similar objective, impersonal manner. Nevertheless, the problem of subjectivity still creeps into the efficiency problem.

Standards for performance will vary from activity to activity. The problems of exterior painting may be relatively minor in Southern California, but extreme in Adak. Costs cannot be directly compared between activities having different wage rates or material procurement advantages or disadvantages. Who is to say, in a purely objective manner, what are proper standards for a particular location? At best these may only be determined historically based on what costs have been in the past to perform certain work. Standards are not necessary based on what it
necessarily (?
should cost to perform the required work.

Ever since the inception of the Navy's controlled maintenance program, attempts have been made to determine which data would be

most valuable in helping evaluate the performance of maintenance organizations. A summary of the work in this field by private industry, illustrated by Chapter III of this study, shows that industry is also concerned with the problem of evaluating maintenance performance. Of particular recent note, however, are experiments at the Navy's Civil Engineering Laboratory, using Operations Research methods, to gain further insight as to what data or characteristics are important in measuring performance.[1] Although the Navy has come a long way in improving methods of determining efficiency, the best answer probably has still eluded all efforts and the present concept of Research and Development work towards this end is to be encouraged and fostered.

Effectiveness and military worth. Effectiveness, as used in this study, deals with the amount of total value or military worth gained by the Navy as a result of utilization of resources for maintenance of Naval shore facilities. The measurement of effectiveness would, in some manner, indicate how much military worth was gained, perhaps in

[1]A partial list of studies undertaken through the Naval Civil Engineering Laboratory is as follows:

a. Factors in Analysis of Maintenance Costs (Task Y-5015-15-06-504)

b. Study to determine methods of distributing maintenance resources (Task Y-F015-15-06-506)

c. Effect of EPS and MME Rating on Backlog of Essential Maintenance (Task Y-F015-06-508)

d. Factors affecting Utilities Consumption and Costs (Task Y-F015-15-06-509)

e. Manpower Input Standards for Transportation Equipment (Task Y-F015-15-06-510)

comparison with how much might have been gained by allocation of the same resources to other projects. Military worth is simply the ability of a particular project or alternative to provide tangible or intangible benefit to a required military capability. Any project having potential military benefit, whether to help morale, restore power service, or to unplug a drain, would have some degree of military worth. The concept of military worth is directly analagous to the economic concept of consumer utility. The keystone to measurement of effectiveness will be shown to be the problem of the measurement of expected military worth to be generated by a particular project.

The first requirement for <u>effectiveness</u> is that the maintenance effort be <u>efficient</u>. Each project which is undertaken should be accomplished with the minimum of resources necessary for the job's satisfactory completion.

In addition, however, it must be determined that each job undertaken was the <u>right</u> job to do at the right <u>time</u>. This requires the maintenance program to be aligned primarily with the operational needs of the Navy and secondarily with the needs of the maintenance program, where the two happen to be in conflict. This may mean that less than completely <u>efficient</u> maintenance of facilities may be most <u>effective</u> in station support. Diversion of maintenance resources to optimum alignment with station mission needs may result in work being done which fosters the mission of the activity, but which may detract from actual maintenance of station facilities.

The need for the maintenance effort to be aligned with Naval Mission requirements brings to light the primary measurement problem. It will be seen from a review of Chapter III of this study that commercial enterprises can obtain a fairly direct evaluation of their maintenance effectiveness by noting the effect on overall production costs of increased (or decreased) maintenance effort. In this case the goals of the company and the resources of the maintenance program are expressed in the same measurable units - money. In the Navy, the maintenance costs are easily measured in dollar terms, but the goals of the organization are difficult to define in any specific, measurable terms, much less a dollar figure. Who can define a unit of "readiness," or "capability?" How much money is one unit of "readiness" worth? How many units of "readiness" are produced by any one particular maintenance project? What is the standard of military worth which should be met by any valid maintenance project?

Subjectivity. Here is a true dilemma. The need for objective measurement of maintenance effectiveness is fairly obvious, but this needed measurement is dependent upon subjective criteria. The very definition of subjectivity would seem to make objective measurement of subjective qualities impossible, at least in the scientific sense.

If one were to assume, at least for the moment, that objective measurement devices are incapable of measuring the subjective valuations of military worth necessary to know the effectiveness of the facilities maintenance program, then the next logical step would be to

determine whether measurement approximations might be utilized which would approximate measurement of military worth well enough so that more rational decisions may be made regarding the problem than would otherwise be the case. There are a host of examples where this is done. School examinations, fitness reports, public opinion polls, intelligence tests, and thousands of other measurement devices are used every day to obtain some valuation of subjective traits. These valuations may not be perfect, but they do at least provide a workable substitute in many cases. Certainly some errors are made. Students can always recall instances where they feel they should have gotten higher (or lower) grades. Some Naval officers are unfairly passed over (others unfairly selected) each year. The system, however, operates with more validity than would be the case without these devices.

Perhaps, if military worth is not susceptible of direct measurement, the various subjective components of military worth such as mission effect, morale effect, appearance effect, readiness effect, etc. could be described in familiar terms so that some numerical value could be attached to these individual segments. The segments could be combined in some fashion and some sort of composite numerical valuation of military worth approximated. If nothing else, an attempt to make this type of analysis might lead to a better understanding of just what the factors are which are important in evaluating military worth.

Whether or not any sort of objective system is developed to measure subjective criteria, subjective ranking of programs and projects in some

preference order _must_ continue to be made in the normal course of business. These decisions are being made now and have always been made. Recommendation 77 of the Dillon Report is one attempt to improve the decision process for facilities management.

Before completely ignoring the possibility of measuring military worth by objective theoretical means, some comments of von Neumann and Morgenstern concerning the ability of evaluating economic "utility" should be mentioned. They note that the problems of evaluating "utility" are reminiscent of the problems with first attempts to measure heat, based on the intuitive concept of one object feeling warmer than another. The reader is cautioned against making any final claims with regard to the impossibility of developing a more precise utility theory. The theory of heat may repeat itself, and nobody can foretell with what ramifications and variations.[2] Certainly it would be wise to stay abreast of developments in current economic theory in order to improve solution of subjective measurement problems. Just as it is impossible to presently prove that utility or military worth can be objectively measured, so it is impossible to prove that at no time in the future will such a development be possible. The future must speak for itself.

II. FOUR STEPS TO EFFECTIVENESS

Having described the basic problems in measurement of effectiveness and explaining the basic terms involved and their nature, it is

[2]John von Neumann and Oskar Morgenstern, _Theory of Games and Economic Behavior_ (second edition; Princeton: Princeton University Press, 1947), pp. 16-17.

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possible to outline four basic steps which must be taken in order for the Navy's facilities maintenance program to be considered effective. These four steps are the following: (1) Determination of deficiencies, (2) Determination of the relative priority of deficiencies, (3) Performing projects efficiently, and (4) Proper resource allocation between activities.

Determination of deficiencies. The starting point for any maintenance project is the determination that a particular situation is deficient in some respect. Maintenance deficiencies in the Navy are determined by complaints of personnel occupying the spaces involved or by routine inspection by Public Works personnel. NAVDOCKS P-322 outlines the Department of Defense criteria for judging the desired level of maintenance for the various types of structures owned by the Navy. This guidance is used in evaluation of reported deficiencies in order to determine whether the deficiency is, indeed, a valid one which requires correction.

Subjective considerations are very much a part of the determination of deficiencies. There is no single point in time at which an alarm bell can be set to ring "Now is the time to paint building S-105" with any rational meaning. One determines whether a building requires a coat of paint or not by looking at it and inspecting the condition of the structure. A personal interpretation is required before the decision can be made as to whether the building requires the paint or not. The NAVDOCKS P-322 guidelines are purposely general in nature, in order to allow flexibility at the field level. This is as it should be. The point to be made here is that any system of measuring maintenance effectiveness must also

include some evaluation of the effectiveness of the manner in which deficiencies are determined, and the relative validity of these deficiencies. This is one of the subjective areas which must be considered for a complete analysis.

Determination of the relative priority of deficiencies. This really is the problem referred to earlier of making sure that the projects undertaken are the ones which should be done. This is always a large problem for the Public Works Officer, due to continual pressures from all sides to divert maintenance resources to where they may benefit a particular office or department to the maximum, but not necessarily where these resources may best serve the general interests of the Navy. So much effort may be expended in caring for fairways and greens on the golf course, that it is difficult to keep the grass around the runways under control. Who is to say just where the dividing line is between how much attention the administration building should get versus the supply building, or between the golf course, the Commanding Officer's yard, or the runway areas. The problem here is deciding which jobs will return the most military worth per dollar spent so that those projects may be accomplished first. Chapter IV of this study proposes a concept for solution of this problem.

Performing projects efficiently. This problem is the one most familiar to the controlled maintenance program. Its solution involves the proper engineered solution to maintenance problems; proper allocation of men, materials and funds to the projects which have been assigned to the shops; and control over sick leave, production losses from delays in

transportation, and similar problems. This is the characteristic of effectiveness which can be most easily measured, through comparison of objective cost accounting data against pre-determined standards. The establishment of the standards, however, has some subjective considerations involved, as has been previously noted.

It should be remembered that an activity may perform very efficiently without being highly effective. By doing only projects of relative simplicity, or where there are a minimum of cross-scheduling problems between work centers, projects may be done very efficiently. If these projects being accomplished are not the projects which should be accomplished to meet the mission of the activity and the Department of Defense maintenance criteria, then the operation will not be effective.

<u>Proper resource allocation between activities</u>. Even though each Naval activity is efficient in its maintenance program, and performs those projects which return the most military worth per dollar cost, the overall Naval maintenance effectiveness will not be maximized unless resources are allocated between <u>activities</u> in a balanced manner. An activity with only meager maintenance funds would be able to apply these funds only to those projects with the highest military worth return. An activity with inordinate resources would be able to accomplish projects of lesser military worth. The overall Naval maintenance effectiveness would be improved if some of the funds from the second activity were transferred to the first activity where the military worth per dollar expended would be higher. This action would increase the total sum of

military worth gained by the Navy's maintenance budget. An optimum system for measurement of maintenance effectiveness would contain some device to evaluate the level of maintenance being attained at each activity in order to spot where redistribution of resources should be made in order to maximize benefit to the Navy. Such an indicator must be capable of withstanding violent attack by representatives of the management bureaus and commands adversely affected by its use.

SUMMARY

Differences in concepts of efficiency and effectiveness have been discussed in this chapter as well as the major role played by subjective analysis in measuring the variables involved in effectiveness measurement. Four basic steps to be taken in obtaining maintenance effectiveness within the Navy have been outlined.

CHAPTER III

MAINTENANCE OUTSIDE THE MILITARY

This chapter discusses the status and concepts of controlled maintenance programs outside the realm of the military, and illustrates program concepts which could assist in increasing the effectiveness of Naval maintenance. Current developments in private industry have been summarized first, followed by a summary of concepts and programs developed by public agencies with the state of California.

I. BASIC INDUSTRIAL CONCEPT

The key to the industrial concept of plant maintenance is the shifting of maintenance costs from their traditional niche as general overhead costs to direct product costs. The goal no longer is lowest-cost maintenance, but lowest-cost product.[1] The measure of effectiveness of the maintenance program is in the same units as the cost of the program - dollars. The problem of evaluating the effectiveness of the maintenance program can then be reasonably well resolved by data of an objective nature gathered through the company's cost control system. As may be seen by a review of the literature summarized in later sections of this chapter, the methods of utilizing this data are varied and numerous.

II. USE OF CONTROLLED MAINTENANCE PROGRAMS BY INDUSTRY

There is still less than complete use of controlled maintenance systems within private industry, despite the time-proven advantages

[1] C. G. Wyder, "Where are we Headed in Maintenance?", in Factory CXXII (January, 1964), 68-71.

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of such systems. In a recent review, it was shown that many maintenance managers are not using proven cost-cutting methods and some had not even adopted basic controls.[2] In an editorial in Factory magazine, it was pointed out that many companies do not pursue their maintenance control potential to the fullest. A good deal of attention has been paid to review of the larger jobs with little analysis of the small jobs. In one plant a team of two engineers was reported to have accumulated savings of $400,000 over a period of eighteen months, out of an annual budget of $2.5 million, by review and analysis of small maintenance jobs costing less than $100.[3]

Despite these occasional editorial reproofs, a reasonable review of the available literature on industrial controlled maintenance systems will show that there are a great many new concepts and procedures which are of the highest sophistication and represent a great deal of high-level analysis and development. A short review of several of the more interesting ideas noted during the literature review constitutes a later portion of this chapter. Of particular note is the increased importance of the maintenance function when an industry has shifted to more automated production techniques. A typical article notes that as machines handle more complicated tasks, fewer human hands are needed to set them in

[2] "Get Maintenance on the Move," in Factory CXXI (September, 1963), pp. 96-7.

[3] L. R. Bittel, "Molehill Mountains in Maintenance," in Factory CXXI (January 1963), pg. 41.

motion, and required human production skills decrease. At the same time, however, the number of hands necessary to keep these machines in operation will increase, the maintenance skills must increase to keep pace with the advanced machine technology, and the pressures for immediate service and repair are extreme due to the high cost and key importance of the automated equipment.[4]

A reasonable conclusion would be that the maintenance effort will become more and more critical to profitable operations, and that a great deal of advance in maintenance concepts and technology will be developed in the future by private industry. The next portion of this chapter contains a review of the more interesting concepts noted during the review of the literature for this study.

III. RECENT INDUSTRIAL MAINTENANCE INNOVATIONS

Scheduling by Mathematical Programming. An article by Wagner, Giglio and Glaser has reported the results of three experiments which explored methods for scheduling preventive maintenance by means of mathematical programming. The report states that the task of scheduling preventive (routine or planned) maintenance involves specifying dates at which manpower is to be allocated to an overhaul of major functional elements. A typical objective is to accomplish required maintenance on a timely basis, keeping to a minimum fluctuations in the aggregate amount of manpower needed.

Three experiments were run, the first two being small scale laboratory experiments. The first experiment assumed 8 fictional

projects to be scheduled over a 10-week period. A table of manpower requirements and sets of possible starting dates were postulated which could lead to 5,184 possible schedules. The second experiment was similar to the first, but postulated personnel requirements and possible starting dates such that 150,000 possible schedules could have been developed. Computerized schedules were developed for both of these problems. The third test involved a full-scale test at an industrial plant where 80 different projects extending over 13 months were to be scheduled. The total number of possible schedules exceeded (42) 10^{60}. A schedule had been manually prepared by the plant maintenance planning staff for comparison purposes. The computer schedule was developed in 30 minutes on an IBM 7090 computer and required only 10 minor manual shiftings in projects. Seventy-eight percent of the projects were scheduled within one month of target date by the manual schedule Ninety-seven percent of the projects were scheduled within one month of target date by the computer. Manpower leveling was also improved by the computer schedule.[5]

Ratio Analysis. Most maintenance programs are concerned with ratios of various types. The most comprehensive list of these various "effectiveness" ratios found was that contained in an article by Victor Z. Priel.

[5]H. M. Wagner, Richard J. Giglio and R. G. Glaser, "Preventive Maintenance Scheduling by Mathematical Programming," in Management Science X (January, 1964) 316-334.

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The ratios will not be listed in this study for lack of space, but are divided into three major areas as follows:

a. Maintenance Effectiveness: Is maintenance manpower being fully utilized, and are its efforts effective?

b. Amount of Maintenance: Is the service it's providing adequate for the plant?

c. Cost of Maintenance: Are the costs of maintenance commensurate with the results achieved?[6]

Critical Path Network Techniques. The increasing use of network techniques is suggested by another factory article. The article contains a good basic summary of "Network Management Techniques," their advantages, problems and references to other articles concerning the technique. Of particular interest were six network examples attached as a fold-out to the basic article illustrating basic uses of these techniques.[7] The advantages of the critical path techniques are likely to become more and more well-known to industry.

Maintenance Gaming. A maintenance business game has been developed to provide insight for participants into some management problems of an organization which has the responsibility for servicing production equipment. The game was developed so that computations

[6]Victor Z. Priel, "20 Ways to Track Maintenance Performance," in Factory CXX, (March, 1962), 88-91.

[7]Marvin Flaks, et. al., "Network Management Techniques" in Factory CXXII, (March, 1964), 86-94.

could be performed by hand or with the aid of a desk calculator in order that it could be played without the aid of a high speed computer. The game can be introduced in a college level course or management development program and completed in two hours. The game provides examples of problems in economic "trade-offs", iterative or trial-and-error problem solutions, waiting line phenomena, and insight into the techniques of business gaming.[8] While apparently aimed toward the development of general business managers the game should have illustrative value to maintenance managers.

Maintenance Prevention (MP). Maintenance Prevention (MP) is a phrase *Factory* magazine has coined to represent what is really a maintenance-oriented design concept. This concept seeks to minimize, through design considerations, the amount of maintenance required by a machine component, the whole machine, a process, a utility service, or a building. Possibly an entire unit may be eliminated through some design change. The elimination of a unit eliminates the maintenance of that unit. In short, the concept willingly accepts higher design or initial equipment cost where the maintenance savings from the use of the higher quality equipment will repay the larger investment in future lower operating and maintenance costs.[9,10]

[8] Forrest Campbell, Donald Pierce, and Paul E. Torgersen, "The Maintenance Game," in *Journal of Industrial Engineering* XV, (January-February, 1964), 30-6.

[9] Carl G. Wyder, "The Expanding Role of Maintenance," in *Factory* CXX (April, 1962), 105.

[10] "Maintenance Prevention is Growing Up," in *Factory* CXXI, (January, 1963), 68-71.

Predictive Maintenance. Predictive Maintenance involves the use of sensing, measuring, or control devices to determine whether there have been significant changes in the physical condition of equipment. Various visual, audio, electronic, pressure, thermal, etc. devices may be used for periodic inspection of equipment in order to determine major change in condition. The idea is not to dismantle equipment for overhaul unless there is some indication that the overhaul is actually needed.[11]

Another example of this technique can be seen in the "Selective Maintenance" program of General Electric. The program results in a "Reliability Index" being developed for the types of equipment under consideration. The reliability index for motors and generators is based upon an analysis of factors such as results of electrical tests, visual inspection, age, motor environment, and types of duty. Each of the factors is assigned a numerical value in accordance with a weighting system established for the motor type. The composite of these weighted evaluated factors is the reliability index for the particular motor under analysis. The motors which have been assigned the least desirable reliability index are then the ones which are overhauled first.[12]

[11]James D. Quinn, "The Real Goal of Maintenance Engineering," in Factory, CXXI (June, 1963), 90-3.

[12]R. L. Hatschek, "Set Maintenance Priority with a Scorecard," in Mill and Factory LXXII (April, 1963), 62-5.

Effectiveness Factors. One use of weighted factors for an over-all maintenance valuation of an electric motor has been mentioned in describing the Predictive Maintenance concept. Another use of weighted factors to measure maintenance effectiveness is described in an article in Mill and Factory. In this General Electric procedure eight different maintenance indicators were assigned weight values with maximums from 5 to 35, the standard total being 100. Where standards are exceeded the overall evaluation may exceed 100. The factors and their respective weights are as follows:

a.	Cost of direct labor actually spent vs. budgeted -	35
b.	Other controllable expenses vs. budgeted -	25
c.	Schedule Effectiveness: number of hours actually spent on construction and repair work orders against hours scheduled for the jobs -	15
d.	Cost Reduction: monthly savings against the target -	5
e.	Downtime Attributable to Maintenance: actual machine downtime vs. a standard (for mechanical trouble) -	5
f.	Call-in Hours Paid: compared to a standard -	5
g.	Manufacturing losses attributable to maintenance: dollar value of scrap caused by maintenance failure against a standard -	5
h.	Backlog trend: number of jobs received against those finished -	5
	Total	100

The numerical valuation for maintenance effectiveness determined in this manner was used as an index and trend of maintenance operations.[13]

Plant Lighting. One approach to the problem of replacement of burned-out lamps is summarized in an article in Supervisory Management. At one plant a regular replacement of all lamps in an area is carried out when the burn-outs, including those which have been replaced since the last general replacement, reach 20% of the total. At this time all fixtures are also cleaned and serviced. Between general replacements burned out lamps are not replaced except in areas where necessary to maintain certain required lighting intensities. A certain number of the replaced lamps which are still functioning are retained as replacements for areas which require some replacements but which are due for general replacement in the near future. The system avoids costly trips and setup time to change lamps individually.[14]

Communications. At one large, multi-storied plant, additional responsiveness and maintenance savings have been accomplished through the use of radio-controlled maintenance organization. The plant has approximately 40 acres of floor space containing many different production divisions and diversified product line. Little of the equipment is new

[13]Ted Metaxas, "Measuring overall maintenance Efficiency," in Mill and Factory LXIX, (December, 1961), 84-7.

[14]"Plant Lighting: The Advantages of Planned Maintenance," in Supervisory Management IX (April, 1964), 54-6.

and there is much emergency maintenance required. To alleviate this problem, four field foremen, each generally responsible for one plant floor, inspect and estimate each job before work begins and stay with the job whenever their help is needed. All paperwork is done at a central headquarters, which controls the operation through 2-way personnel-carried radios.[15]

Summary of industrial innovations. The cited examples illustrate the level of sophistication and development of maintenance concepts in private industry. Although many concerns do not make adequate use of advanced controlled maintenance techniques, it is equally obvious that many other concerns have advanced to a very high conceptual state. Future developments in the industrial family should be continually monitored for possible application to Naval needs.

Most of these developments deal with improving the efficiency of maintenance operations. Very few deal with the problem of determining whether the work being done is actually the work which should be done considering all of the circumstances. Mr. Quinn's article notes that doing the maintenance job more efficiently seems to be the principal objective of many maintenance engineers; but worthy as this objective is, a basic question is being overlooked: "Is the work being done really necessary?" Quinn notes that even with an operational controlled

[15] "Radio Expedites Central Control of Maintenance," in Factory CXXII (January, 1964), 72-5.

maintenance system, there are frequent cases where inadequate analysis of the need for all work being performed is carried out.[16] Despite the advancing technology and improvements in project efficiency, the literature of private industry offers no magic cure for the problem of determining which projects are the right ones to be done. The work may be efficient, but not necessarily as effective in contributing to profitability as it should be. The Naval maintenance program has the same effectiveness problem, but with the added handicap of the lack of an overall "profitability" indicator.

IV. MAINTENANCE WITHIN STATE AND LOCAL AGENCIES

Decentralization. From correspondence received it is evident that decentralization is a predominant feature of the maintenance efforts of public agencies. An initial letter was addressed to the State Auditor General asking for information on criteria used by the State of California in evaluating the State's maintenance program. The reply stated that the Department of General Services was the agency having the principal responsibility for State buildings and grounds, but that this responsibility was decentralized to a high degree. It was suggested that several other specific agencies be contacted separately to obtain information on maintenance within their areas.[17]

[16] Quinn, loc. cit.

[17] State of California, Office of the Auditor General, letter of February 3, 1964, signed by William H. Merrifield, Auditor General.

The Department of General Services stated that the State of California had no prepared summary of the State's facilities maintenance policies or specific criteria for budgeting or evaluating the maintenance "product." The opinion was expressed that expenditures for maintenance of physical facilities can only be standardized when dealing with two or more installations which are practically identical. It was thought necessary to review each individual installation to provide the proper resources for adequate maintenance The proper level of maintenance was considered to be a matter of judgment which could not be resolved soon enough by any formula to convince budget analysts of the necessity for additional maintenance funds. It was further stated that some time ago, the State Division of Architecture had a special crew which visited all State institutions and recommended maintenance projects and programs. However, it had been determined that the expenses of such a staff were not warranted for the value obtained and that it would be better for the individual institutions and their headquarters offices to establish their own maintenance programs.[18] Replies from the Department of Finance, the Joint Legislative Committee, California Legislature and the Division of Highways further indicate decentralized operation and establishment of localized criteria for effective maintenance effort.[19, 20]

[18]State of California, Department of General Services, letter of March 30, 1964, signed by A. W. Collins, Assistant Director.

[19]State of California, Department of Finance, letter of March 19, 1964, signed by F. J. Murphy, Senior Budget Analyst.

[20]State of California Joint Legislative Budget Committee, California Legislature, letter of March 13, 1964 signed by A. Alan Post, Legislative Analyst.

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The Division of Highways does review centrally the results of each district with the objective of maintaining a uniform standard throughout the state for similar road and traffic conditions. Close control of highway maintenance funds is maintained by the Maintenance Engineer in Headquarters. Any work other than routine maintenance must be specifically authorized and a work order allotment issued prior to the work being undertaken in the field. In this category are items of major storm damage repair, preventive maintenance measures, bridge repairs exceeding $1000 per bridge, and similar activities.[21] The operation of the Division of Highways seems to more closely approximate that of the Bureau of Yards and Docks than any of the other State agencies from which replies were received.

Ratio Analysis. Those few agencies which replied most specifically to the question of how they measured their maintenance effectiveness placed most emphasis on ratio analysis. The Division of Highways plans for numbers of maintenance personnel on a historical basis. The budget is then based on the personnel level, applying a factor for the cost of the maintenance operation per man, including necessary equipment and materials to perform all normal maintenance. To equalize the work load, the local organizations are compared on the basis of the number of lane miles maintained per man. In addition, the number of acres of landscaping maintained per man is also considered. Some other features

[21]State of California, Division of Highways, letter of March 3, 1964, signed by C. J. Brown, Asst. Maintenance Engineer.

are considered, however, such as the number of electrical safety devices or steel structures which may require special maintenance operations.[22]

The University of California compares maintenance costs in relation to outside gross square footage of building area between various campuses of the University, making an analysis to evaluate deviations due to local conditions. As a point of interest, reference was made in their letter to BUDOCKS publications for obtaining further information on yardsticks and standards.[23]

The County of Los Angeles stated that it had no schedule of maintenance standards to provide, but that for the past several years maintenance of new space had been budgeted at an average of 20¢ per square foot. It was further stated that one custodian normally services about 8000 square feet, although other formulas for staffing of custodial services had been worked out and could be made available upon request.[24]

Although the letter requesting information from these agencies was not phrased in such a way as to obtain detailed data on the current status of implementation of a controlled maintenance program at each of the agencies, the general impression from review of the correspondence received was that the degree of control over the public agencies

[22] Ibid.

[23] University of California letter of March 25, 1964, signed by S. A. Musser, University Engineer - Maintenance and Operations.

[24] County of Los Angeles, Mechanical Department, letter of March 4, 1964 signed by A. L. Journey, Assistant Chief Deputy.

maintenance effort was not equal to that of the Naval program, nor of the level of sophistication which has been developed in portions of private industry. Perhaps this has been due to the lack of centralized review of maintenance costs and effectiveness, and to the ever-present public service problem of the lack of a "profit" criterion by which the effectiveness of the organization may be judged. It was refreshing to note, however, that the City of Los Angeles outlined the development of a program to determine quantitative evaluation methods for building maintenance and operation. Comparative effort values for similar work are soon to be a part of their cost and management reports. Recently, the introduction of task-area units into the cost-keeping system produced their first task-unit cost report. The annual cost per square foot for plumbing systems maintenance for a given building is now available, as are similar unit costs for other maintenance and operations tasks. The planned periodic inspection program has not, however, yet been implemented.[25] The obvious intent of the new program will be to develop a well-controlled maintenance system.

V. SUMMARY

Private industry, and to a limited extent, some public agencies, have developed many sophisticated innovations in improving the efficiency of their maintenance efforts. These developments should be monitored continually by the Bureau of Yards and Docks. Very little

[25]City of Los Angeles, Department of Public Works, File Number 550.0-Collins letter of February 26, 1964 signed by W. R. Blakely, Director, Bureau of Public Buildings.

information, however, was found which bears upon the problem of measurement of effectiveness of the maintenance effort where the profit motive is lacking. The concepts of Predictive Maintenance and Maintenance Prevention do bear directly upon the Navy's effectiveness problem. At least one example of "measuring" effectiveness with the aid of a weighted evaluation system was noted.

CHAPTER IV

A PROPOSED USE OF MILITARY WORTH CONCEPTS

The problems of measurement of military worth have been discussed in Chapter II. In addition, some comments of Oskar Morgenstern are appropriate here. He has noted the need for more research by the Department of Defense in the area of military worth determination. The development of a more workable method of determining military worth of various alternatives would be more important than to introduce some further, purely technological advance in some weapons system. It would improve the use of all of them.[1]

I. THE CONCEPT

It may be recalled that two of the four steps necessary for effective maintenance operation involved allocation of resources. One decision was at the activity level in determining which projects to perform; the other was at the Bureau or Field Engineering Office level in deciding where best to allocate resources between activities. The position taken in this study has been that the allocation decision should be based on the determination of which alternative provides the greatest return in military worth per dollar spent.

If the military worth, or a suitable approximation thereof, for each alternative could be determined on a numerical scale, the allocation problem would be basically solved. One would calculate the military

[1] Oskar Morgenstern, The Question of National Defense, (New York: Random House, 1959), pp. 203-5.

worth of each project, divide each military worth figure by the respective estimated total cost of the project, and do those projects first which provide the highest military worth per dollar expended.

One immediate objection to this theoretical concept comes from the association of the concept of military worth with the economic concept of consumer utility. In order for the military worth valuations to be meaningful for preferential ordering when divided by the project cost, the valuation of military worth must possess cardinal ordering properties. In order for a $1000 project to return the same military worth per dollar expended as a $500 dollar project, the valuation of military worth for the $1000 project must be twice that of the military worth valuation of the $500 project. The most accepted economic utility theory holds that consumer utility preferences cannot be expressed by cardinal scales, but only by ordinal preference. One can say that a certain project is "better" than another one but it is not rational to say that one project is twice as "good" as another one, since "utility" is an abstract term with no measurable properties. Utility is really a name given to a subjective concept to explain observable behavior of individuals and their market choices.[2]

Another problem might develop if attempts to use such a system are broadened to use by more than one individual. This might be the

[2]For a more complete review of contemporary utility theory and an excellent bibliography for further study see: Ernest W. Adams, "Survey of Bernoullian Utility Theory," Mathematical Thinking in the Measurement of Behavior, Herbert Solomon, editor, (Glencoe, Illinois: The Free Press, 1960), pp. 151-268.

case if a system developed for use at one activity were to be adopted by all activities within the region of a Field Engineering Office, the system then to be used in evaluating needs of one activity versus another in terms of the expected military worth for available resources. This problem stems from the inability to transfer meaning of one person's "worth" or "utility" to another person. Individuals have different criteria of value, and comparisons of different utility valuations by different people are illogical. Criteria for one activity commander will appear different from that of another activity commander, and valuations of military worth may have been based on different command policies. Individual criteria which may work well at a particular activity may not be appropriate for inter-activity comparisons.

There is, however, far from universal agreement that "utility" is solely an ordinal concept. The classical contemporary discussion on this point is contained in a text by Von Neumann and Morgenstern. If an individual prefers alternative C to A and prefers alternative A to B, but prefers A to an alternative situation where there is a 50% probability of getting B and a 50% probability of getting C, a plausible argument may be made that his preference of A over B is in excess of his preference of C over A. Determination of the relative combination of probabilities of getting B or C for which the individual claims to be indifferent to an alternative choice of A may provide some criterion for measuring the relative preference of the individual for B and C in comparison with A.[3]

[3]John von Neumann and Oskar Morgenstern, Theory of Games and Economic Behavior, (second edition; Princeton: Princeton University Press, 1947) pp. 8-20.

From another point of view, it is felt that if an individual states he is undecided whether to buy two items of article D or one item of article E with the same resources, then one could do somewhat better than to say that the individual merely places his preference for one article of E above that of one article of D.

In answering the problem of inter-transference of "utility" or "worth" values, it should be noted that the concept of military worth has one significant difference from that of consumer utility. Military worth evaluations should not be personal in nature. They should be based on high level policy guidance, common to most, if not all, activities. There are still problems in using a common military worth system for allocation of resources between activities, but these are more mechanical than theoretical. Basic decisions at all activities should be in the best interests of the Navy. Additional comments on this subject are placed near the end of this chapter.

From a realistic viewpoint, any sort of solution to the problem of measurement of utility or military worth in the near future will have to be satisfied with an approximation to a final mathematical, objective solution. The theory just has not advanced to the state where one person's utility preferences can be precisely measured in numerical terms for any predictive purposes. This study takes the position, however, that a decision model could be developed in the interim, utilizing cardinal properties of a military worth scale, which could assist the decision-maker, on at least the local level, in his decisions

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as to where best to allocate his maintenance resources. While not at all theoretically or mathematically pure, this system would provide numerical scales for certain factors important to the decision. Values for these factors could be combined in some designated manner so as to reach a derived numerical approximation for the military worth to be expected from the alternative under consideration. The approximation of the military worth of the project could then be divided by the total cost of the project to determine the military worth of the project per dollar expended. Projects contributing the most per dollar to the military worth of the Navy would be done first, and those projects which have the least return would be done last, or not at all.

Although this system cannot be completely supported in an objective theoretical way, it at least is an attempt to develop a system which would work in the manner in which the decision-maker would <u>want</u> such a system to work, and perhaps in the way in which the decision-maker should <u>think</u> pending the development of a completely pure theoretical model.

II. THE SYSTEM

Such a system has been developed by this study, using rather arbitrary factors. Two small introductory experiments were conducted in an attempt to see if such a system, developed through more detailed analysis, might be of service. The complete description of factors, their weights, computational steps, and other procedures of these experiments are contained in Appendix I. The basic concept and

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general outline of procedure is covered here.

Two sets of factors were used. The first set consisted of two so-called "Qualitative Factors," which were graded without consideration of the scope or cost of the projects. As actually used, these factors were intended to help answer the questions: (1) "To what extent is the proposed work aligned with the mission needs of the activity?", and (2) "To what extent will the cost of the project be returned during operation of the facility involved?"

The second set of factors consisted of three "Quantitative Factors," which were intended to provide a means to adjust the military worth score for the magnitude of the benefits to be realized for each alternative project. These factors were intended to help answer the questions: (1) "How much of the mission of the activity is affected by this project?", (2) "How great are the expected opportunity cost savings in absolute magnitude?", and, (3) "To what extent is the project postponable without loss of major benefits?"

Specific guidance for grading each factor is contained in Tables I and II, Appendix I.

Emphasis was placed on keeping the evaluation effort simple and concise, although some pure theory may have been sacrificed in so doing. For example, no attempt was made to determine costs beyond that required for the initial work. However, the personnel acting as evaluators during the experiments were expected to look at the savings

factors from the point of view of opportunity costs and effects over more than just the period immediately following the actual work.

The "Qualitative Factors" for each project were summed together in a single column. The "Quantitative Factors" for each project were also summed. For each project, the "Qualitative Factor" sum was then multiplied by the "Quantitative Factor" sum to give a product simulating the military worth of that project. This product was then divided by the estimated cost of the project in hundreds of dollars to obtain a quotient simulating the military worth of the project per unit of project cost. The projects were then arranged in order of relative priority with the project providing the highest military worth per dollar at the top, and the project with the least military worth per dollar at the bottom. This priority list was then compared with a priority list of the same projects prepared in advance of the experiment by the same evaluator.

Specific conclusions are found at the end of Appendix I. In general, however, the general concept and rationale of the process appear sound although some revisions are necessary. A more detailed study of the concept, preceded by a comprehensive factor analysis, and more extensive experiments at larger installations would be worthwhile.

III. USE OF THE CONCEPT FOR INTER-ACTIVITY COMPARISON

Were the system to be used at an activity continuously, it would soon be evident that there would develop a certain military worth/dollar level above which a project must be rated or it would stand little chance of being accomplished. This value might be called the <u>effectiveness</u>

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level of the activity for it represents the effective return per dollar that the activity is able to gain, at the margin, for its maintenance effort. If the effectiveness level of the activity is, for example, 5.0, then allocation of one more maintenance dollar to the activity should result in a military worth return at the 5.0 level.

If another activity uses the same system, and utilizes the same criteria for assignment of military worth factor values, it will make similar decisions and also find that it is usually able to accomplish those jobs falling above a certain effectiveness level, but those jobs whose rating falls below this effectiveness level never seem to get accomplished. This second activity might find that its effectiveness level is 7.0. If this is the case, and if all factor judgments at both activities are made on the basis of the same criteria, then maintenance resources should be diverted from the first activity and reallocated to the second activity, since 2 more units of military worth per dollar may be obtained from maintenance funds at the second activity than at the first activity.

If enough resources are diverted from the first activity, it will find that the effectiveness level of its maintenance effort will rise above 5.0. There are now less resources available and only those jobs with military worth/dollar ratios of, say, 5.5 or higher seem to get accomplished. In the meantime, the second activity, having received resources from the first, will find that its effectiveness level has decreased, perhaps to 6.5. More resources are now available to do

jobs whose military worth/dollar ratio is below 7.0. If this re-allocation process continues long enough, the point will be reached where the effectiveness levels of the two activities are equal, perhaps at 6.0. This would mean that allocation of an additional maintenance dollar to either station would result in the same return in military worth. If this equilibrium condition existed throughout the Navy at all activities, the available maintenance resources would have been distributed in the most optimum manner possible, for any reallocation of funds from this condition would result in a lowering of the effectiveness level of the activity to which the funds are assigned and a raising of the effectiveness level of the activity from which the funds were taken. The lower return of military worth at one activity would represent an opportunity cost. For optimum effectiveness resources should be re-allocated so that the equilibrium condition were regained.

This concept is analogous to the concepts of marginal consumer utility presented in economic theory.[4] The concept illustrates a marvelous advantage of being able to measure military worth in terms meaningful for inter-activity comparison. The analysis does not say whether or not the specific proposed system of approximating a numerical value of military worth at each activity would guarantee such splendid results for the purposes of resource allocation between activities.

[4]For a basic review of marginal utility concepts see: H. H. Liebhafsky, The Nature of Price Theory, (Homewood, Ill.: The Dorsey Press, Inc., 1963), pp. 82-92.

It is probable that a system based on approximations of military worth calculated by the activity would not lend itself to automatic resource allocation between activities. Each activity would tend to warp the system by evaluating their projects higher in military worth than would be the case based on rational evaluation. By so doing, the activity would hope to receive additional maintenance resources. At the same time, the effectiveness of the system for allocation decisions at the activity might decrease if the system were "warped" unevenly.

Another problem would be the need for the reviewing agency to either treat all activities as equally vital to the needs of the Navy (obviously not the case) or else apply priority factors to each of the activities to determine proper allocations. If one activity were more vital than another, its calculated level of effectiveness could be allowed to be lower than that of a lesser activity. The Bureau of Yards and Docks should not begin assigning priority values between activities. This guidance would have to come from higher authority, who may not wish to make this public distinction between activities.

The conclusion of this study will be that for the near future, a system such as proposed in this Chapter would be ineffective in determining the proper allocation of maintenance resources between activities.

IV. SUMMARY

The concept of a numerical system to approximate an evaluation of the military worth of proposed maintenance projects has been proposed to assist in allocating maintenance resources at the activity level. The

system has been tested in two small experiments as reported in Appendix I to this study. The conclusions were that the basic concept appears worthy of further investigation on a larger scale.

CHAPTER V

THE MEASUREMENT OF EFFECTIVENESS

Thus far, this study has discussed what the meaning of effectiveness is, the types of programs undertaken by both industry and government in evaluating effectiveness, and one proposal to help in attaining increased effectiveness at the local level. This chapter attempts to pull together the problems to be encountered in trying to measure maintenance effectiveness, first outlining the characteristics of the "ideal" measurement system, followed by a discussion of necessary concepts and policies to be followed in determining how the measurement process should best be carried out. Recommendations for further study conclude the chapter.

I. THE IDEAL SYSTEM

The ideal system for measuring effectiveness would have some basic characteristics. The result should be of a numerical nature, incorporating evaluations of the various important factors and criteria contributing to effectiveness. In short, the final results should resemble a scorecard, showing scores for the various effectiveness factors, and combining these scores in some weighted manner to lead to a logical numerical result. The over-all rating should also be in units which represent some meaning as to the relative maintenance capabilities of the activities evaluated.

If this precept is accepted, the next questions are: (1) "What are the criteria which must be evaluated by the system?", and (2) "What

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are the units in which the over-all effectiveness measure should be displayed?"

Criteria. The actual selection of criteria by which maintenance effectiveness is to be judged must come from the top level of the Naval organization. Only here can the effects of all various Navy programs be felt. If the Secretary of Defense were to establish the criteria for effectiveness of facilities maintenance in specific, written terms, the measurement problem would be cleared considerably, the remaining problem being only to decide how best to evaluate the published specific criteria. Any complete criteria statement must include a listing of the specific factors which affect the capability being measured and the relative weights to be assigned to each factor in determining the final composite evaluation.

One example of defining such criteria is contained in Tables I and II of Appendix I. In proposing the use of military worth concepts in Chapter IV, the combination of these factors was said to approximate the military worth of a particular maintenance project. These criteria undoubtedly need revision before Navy-wide acceptance should be proposed, but they at least illustrate the type of criteria which must be developed before any meaningful measurement attempt can be made. By utilizing published criteria of this type, five relatively simple decisions were substituted for one more difficult decision, with a reasonable indication that superior results may have been achieved. The problem of criteria then resolves itself basically to two problems: (1) that of selecting proper factors for evaluation, and (2) weighting the selected factors so as to result in a rational effectiveness "measurement."

Factors. As a minimum, each of the basic steps toward achieving effectiveness should be evaluated. From a review of Chapter II, these factors would be: (1) the validity of deficiencies, (2) the ability of the organization to correct deficiencies in the right priority order, and (3) the efficiency of the activity's maintenance effort for those projects accomplished. An evaluation of the effectiveness of the Navy-wide maintenance effort would also include an evaluation of the fourth step to effectiveness - the over-all ability to allocate Navy maintenance resources where most needed. Since this study is primarily concerned with evaluation of the maintenance effectiveness within the Navy, this factor will be ignored for the moment. It is assumed that if the measurement system is valid and reliable, then the resource allocation problem between activities will be automatically resolved correctly. One purpose of the ideal measurement device will be to make this inter-activity allocation decision.

In addition to the three basic factors discussed above, other factors need to be evaluated if a more complete picture of the effectiveness of an activity's maintenance effort is to be evaluated. One of these factors would be the determination of something akin to the "effectiveness level" discussed at the end of Chapter IV. This figure was said to be the marginal amount of military worth returned per maintenance dollar expended by an activity, and would help suggest where maintenance resources should be allocated for maximum benefit.

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Another factor which may or may not be required, but for which provision should be made, would be a rating of relative importance of one activity over another. If an allocation decision must be made between two activities of otherwise equal maintenance effectiveness, the allocation should be made to that activity whose function is of greatest "military worth" to the Navy. This possibility has been noted in Chapter IV. The Chief of Naval Operations, assisted by the Fleet Activities Command, should make this decision when it is required.

A last major factor which may be helpful would be an over-all evaluation of the material condition of the activity resulting from the current maintenance effort. This factor would help show how well one station is being maintained in comparison with others and would affect the degree to which maintenance resources may require readjustment.

Factor weights. The problem of assigning proper factor weights so that the factor evaluations may be combined into one representative number is obviously a key one. Nevertheless, there is little new to discuss concerning this problem, since the logic is straightforward. If one factor is thought to be twice as important as another factor, then the value of the first factor should be weighted by a factor of two in comparison with the second factor. The only real problem here is the decision as to which factors are most important, and by how much in comparison with the other factors. This decision requires the same sort of analysis as did the actual determination of criteria factors. It is not known whether there is any "right" answer to this problem, but the factors should be

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weighted in some manner to correspond to the professional opinions of top management, preferably as supported by some experimental work. The only check on the correctness of the factor weights is whether or not the resultant combination of factors and weights results in decisions which are reasonable to the managers of the programs. This check is actually a check of the ability of the system to evaluate both aspects of criteria - use of proper factors as well as the proper weights.

Measurement units. There is no clean answer to the problem of proper choice of units for the effectiveness evaluation. Whatever the name which may be given to the final unit of measure of effectiveness, it should purport to show the relative return of military worth of maintenance effort per dollar expended at the activity. In addition, the separate factors should be scored by some standard numerical technique by which that factor could rationally be compared, as an entity, with the same factor for another activity. The values of these sub-factors have been shown to be subjective in nature, and the units of evaluation are really units of "goodness," or "worth," or "capability", which are not directly measured from observable physical phenomenon. The units involved are rather arbitrary and have abstract meaning, a very undesirable situation from a scientific viewpoint. The evaluation attempt, however, should serve to improve the maintenance evaluation procedures now in use, in much the same way that the fitness report system is intended to improve the officer selection process over what would be the situation without the evaluation technique. One should not give up the measurement

attempt simply because it is not convenient or obvious how the measurement should be done. Perhaps the term "evaluation" should be substituted for "measurement" when considering problems of the type discussed in this study.

II. MEASUREMENT OF CRITERIA

Having outlined the characteristics of the ideal system, the next logical step would be to analyze how to go about the actual measurement or evaluation of effectiveness at a particular activity. It is at this point that the discussion begins to leave the scope of this study. It is impossible in this study to comment on specifically how each of the effectiveness factors should or could be measured, and no experimental work in this area has been conducted within this study. Such analyses and experiments should be undertaken as logical extension of the concepts outlined in this study.

There are, however, several basic concepts which should be followed in the detailed measurement analysis, when made.

The first step is to concede frankly the subjective nature of the problem. The optimum answer is not just a matter of more detailed engineering research and statistical analysis. Engineering or statistical studies do serve a worthwhile purpose in those areas where they are appropriate (such as the cited studies at the Navy's Civil Engineering Laboratory), but subjective analysis is even required in evaluating the results of such experiments.

A second major consideration is the need for the personnel of the Field Engineering Activities to be well informed on the problems and needs of the activities within their regions of responsibility. A casual once-a-year walk-through of the activity involved will not be adequate. More frequent liaison on the working level must be a part of the measurement system. In addition, the eventual effect of the Fleet Activities Command must be considered and taken into account. The Fleet Activities Commander's requirements in an area will be of paramount importance, and Field Engineering Office personnel must work closely with this organization, being fully cognizant of conflicts which may arise due to the inherent conflict of centralized operational authority versus centralized maintenance support.

Of equal importance should be the desire of local commanders and Public Works Officers to hold the interests of the Navy as a whole ahead of the local interests of an activity, where the two may happen to be in conflict. Without going into this problem to any great extent, the attempt should be made to approach allocation decisions with as nearly an objective view as possible, trying not to attach inordinate valuations to local projects not in the best interests of the overall broad needs of the Navy. Projects which are primarily a result of personal preferences such as unnecessary reassignment of office spaces or changes in equipment arrangement with no change in capacity should be avoided. One of the advantages of the proposed priority system of the previous chapter is thought to be the ability of such a system to determine project preference

with a minimum of distraction by personal prejudice. The results of the analysis cannot be foretold with accuracy by intuitive means.

The measurement solution may also require assignment of something similar to the Level of Maintenance Classification (LMC) Code described by the Public Works Management Improvements Draft.[1] Exception is taken in this study, however, to the principle that multiple classifications within a particular facility are to be avoided. A hangar may provide more direct support to an air station's mission than the administrative offices, hence rating a higher maintenance level classification; but the administrative office spaces in the hangar may be of less importance to the mission of the station than the central administrative offices. Supply buildings often provide administrative spaces as well as warehousing facilities under one roof. The use of multi-mission facilities necessarily requires frequent multi-classifications. Otherwise an illogical system is developed which may contribute to more serious allocation errors than the original intuitive system. The concept of identifying maintenance with the mission of the activity and its tenant activities is certainly supported by this study, as has been made clear earlier.

Another very important analysis and decision to be made is to determine the depth to which attempts should be made in factoring,

[1] United States Department of the Navy, Bureau of Yards and Docks, Public Works Management Improvements (Draft), (Washington: The Bureau of Yards and Docks, October, 1963), pp. 19-20.

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weighting, and evaluating various criteria. In all likelihood, the more detailed the measurement analysis, the more accurate and meaningful the resultant evaluation will be. It will also be more costly than more modest efforts. There must exist some level of detailed analysis beyond which the added return in knowledge and control does not pay for the added expense of evaluation in minutia. Additional control devices and information are not desired if they are obtained at inordinate cost. An analysis must be made of what the ideal evaluation system is worth to the Navy in terms of the additional military worth accruing from better allocation of resources, better supervision of field activities, the resultant improvement in effectiveness of assigned resources, and the ability of the system to substantiate a more effective budget level. To this must be compared the cost of obtaining the data to make the system work properly.

The Bureau of Yards and Docks now receives a voluminous amount of data having some bearing on the efficiency/effectiveness of the facilities maintenance program. Perhaps ninety per cent of the result is presently being obtained with only ten per cent of maximum effort. Maybe only slightly more (or less) data very similar to that which is now available is all that is needed for an optimum system. A review in detail of this problem of scope using Operations Research techniques should be one of the initial steps in a further look at the measurement of facilities effectiveness.

The last major concept of advanced measurement analysis mentioned here is the need for a teaming of personnel of an Operations Analysis or Operations Research background to assist top management in resolving the measurement problem. The problem is one that will require personnel from many backgrounds if a reasonable solution may be expected. No one individual or one approach will suffice for ultimate success.

It may appear unusual that a paper entitled The Measurement of Naval Facilities Maintenance Effectiveness has discussed only to a very limited extent the actual measurement portion of the problem. It has been the stated intent of this study to deal primarily with the conceptual aspects of the effectiveness measurement problem, since this basic concept appears to be the first need in the solution of the effectiveness measurement problem. The conceptual phase of the problem begins to fade once the factorial criteria has been defined clearly and the attempts are begun to actually perform measurement of these factors. Further discussion of specific criteria formats or evaluation techniques must await more detailed analysis and experiment.

III. RECOMMENDATIONS FOR FURTHER STUDY

During the course of this study it has become evident that much more research needs to be done to improve the measurement of maintenance effectiveness in the Navy. Some of the more necessary studies are listed below.

Continue NCEL projects. The recent assignment of statistical analysis projects to the Naval Civil Engineering Laboratory represents a great stride forward in analysis by the Bureau of Yards and Docks. Projects such as those which have been undertaken are just the type which may prove of real worth in evaluating the maintenance effort.

Cost analysis to determine needed measurement depth. This study would attempt to establish the proper level of data-collection and control beyond which additional data or controls would not be warranted. This study would attempt to find out if, indeed, the Navy has perhaps already solved "ninety per cent of the effectiveness measurement problem with only ten per cent of the effort" such that more detailed information might actually not be worthwhile. The results of the study might very well indicate that the other studies are impractical at the present time. It should be remembered, however, that whenever significant changes occur in the parameters of such a study, such as the development of inexpensive data-processing equipment, the study must be reviewed, for the results may have changed.

Further experiments with military worth concepts. The attempts to develop better means of measuring military worth should be continued, not only for allocation of maintenance resources, but for the larger and more critical problems in all sectors of the Navy. Closely aligned with this would be further studies to improve the ability to evaluate subjective criteria by "quasi-objective" approximations.

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[illegible]

[illegible]

Scorecard analysis. Experiments with different types of "scorecards" for activity effectiveness evaluation may be useful in attempting to arrive at one combination of various factors which could provide a reasonable approximation to the effectiveness evaluation of individual activities. Attempts to grade activities, even based on data presently available, may result in real advances in use of presently available data for closer approximation of maintenance effectiveness for individual activity and Navy-wide operations.

IV. SUMMARY

This chapter has outlined the characteristics of an ideal measurement system, discussing the selection of effectiveness criteria and the problem of selection of measurement units. Conceptual problems of actual measurement are then introduced and recommendations for certain further research outlined.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Implementation of recommendations of the Review of the Management of the Department of the Navy, Department of Defense policy trends, and a probable continuation of present difficulties in obtaining adequate facilities maintenance funds will require the Bureau of Yards and Docks to develop better means of increasing the effectiveness of facilities maintenance. A key aid in increasing effectiveness would be the ability to measure the effectiveness of the facilities maintenance program in meaningful terms.

Efficiency is defined as a measure of the technological ability to achieve a defined maintenance output with a minimum of resources. Effectiveness is concerned with the broader goal of realizing the best possible return of maintenance military worth for the resources expended. Effectiveness depends on operational efficiency in completing projects undertaken, but also depends on optimizing the choice of projects to be undertaken, as well as optimizing the allocation of resources among different Naval activities to best meet the needs of the Naval Service. Through this analysis the need for objective evaluation of subjective criteria has been observed. Four basic steps to attain maintenance effectiveness are said to be: (1) Determination of valid deficiencies, (2) Determination of the relative priority of valid deficiencies, (3) Performing projects efficiently, and, (4) Proper resource allocation between activities.

A review was made of developments in the maintenance area among private industry and public agencies within the State of California. The basic industrial concept concerns the use of maintenance resources and programs so as to produce, not the lowest cost maintenance, but the lowest cost product. The criteria of effectiveness in private industry has the same units as the resources involved - money. This criteria cannot normally be extended as guidelines for public-supported agencies. Although there are some instances of a lack of use of controlled maintenance techniques by private industry, the advantages of such systems appear to be well understood and commonly have been adopted. Much sophisticated development work has been done within private industry. This work should be continually monitored by the Bureau of Yards and Docks. A common feature of maintenance programs of public agencies within the State of California was the decentralization of maintenance authority and responsibility. From the data available, the acceptance of concepts of controlled maintenance appeared to be less within these public agencies than within private industry. No clear-cut answer to the problem of measurement of maintenance effectiveness within a non-profit service organization was found by a review of the literature available.

The study proposes a conceptual system to attempt to aid in determining the relative priority order of maintenance work requests at the local level. The system attempts to simulate an evaluation of the military worth of a proposed maintenance project in cardinal numerical

terms, which can be related to the cost of the project to obtain a military worth per dollar cost evaluation for each project under consideration. Various projects may then be ranked in relative order by placing those projects with the highest military worth per dollar cost valuation at the top of the priority list. Two small introductory experiments were held to make a rough check of the concept and to indicate whether further study of application of the concept would be worthwhile. Conclusions were that the results of the use of the system correlated poorly with intuitive preference lists, but that the concept should be further evaluated, since some evidence was available to indicate that the intuitive preference order to which the results of the experiments were compared may not have been an appropriate standard for comparison. The intuitive lists showed some inconsistencies, further indicating the need for a system of a more objective nature to assist in making these decisions.

An ideal effectiveness measurement system was outlined, providing for evaluation of several factors selected to fit effectiveness criteria established at the highest Naval level. Suggested factors would be: (1) the validity of maintenance deficiencies, (2) the ability of the organization to correct deficiencies in the right priority order, (3) the efficiency of an activity's maintenance effort, (4) the "effectiveness level" of an activity, (5) the relative importance to the Naval mission of one activity relative to another (if necessary), and, (6) the material condition of the activity being evaluated. Proper factor weights should be selected so as to combine separate factor evaluations into the most reasonable

composite score. The final units of the measure of effectiveness should indicate the relative return of military worth of maintenance effort per dollar expended at the activity being evaluated. Several basic concepts to be followed in further research to determine actual measurement methods for the factors selected were discussed. Further study should involve: (1) continuation of current studies at the Naval Civil Engineering Laboratory, (2) cost analysis to determine needed depth of measurement, (3) further experiments with military worth concepts, and (4) experiments with scorecard analysis to develop a proper evaluation format and measurement methods. Of particular importance is the need to decide, on the basis of a cost analysis study, the degree to which additional data is needed in order to control facilities maintenance programs more effectively than is the present case.

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APPENDIX I

APPENDIX I

AN INTRODUCTORY EXPERIMENT TO CHECK THE CAPABILITY OF A PROPOSED SYSTEM TO ESTABLISH RELATIVE PRIORITY OF MAINTENANCE WORK REQUESTS

I. ABSTRACT

A proposed system for determining preference order of maintenance work requests was examined through introductory experiments performed at two small Naval shore installations. Although the preference ranking determined by the proposed method did not correlate well with a separate ranking of the same work requests by intuitive methods, the calculated preference order was deemed acceptable by the activity representatives performing the evaluations, with the exception of 2 of the 25 work requests in each case. It is believed that the concept tested is rational and workable, but that the specific factors and grading system could be improved through more detailed study.

II. PURPOSE

The purpose of the experiments was to make an introductory check of the concept and ability of a proposed system to develop a workload priority listing by determining a simulated military worth per dollar cost rating for each of the examined work requests. The results of the experiments were to provide background information for a proposed use of military worth concepts as a portion of a student Research Paper on the subject of the measurement of effectiveness of the Navy's Facilities Maintenance Program.

III. EXPERIMENT NO. 1

<u>Date of Experiment</u>. 16-17 April, 1964

<u>Location</u>. U. S. Naval Air Facility, Monterey, California

<u>Procedure</u>. Only work requests estimated to cost more than $100 were utilized in the experiment in order to stay out of the range of service call project scope. A sample size of 25 work requests were arbitrarily picked as being large enough to make a preference ranking moderately difficult by normal intuitive means and yet not so large as to make calculation of the derived ranking order too time-consuming, considering this as only an introductory experiment.

In cooperation with the Public Works Officer at NAF, Monterey, twenty-five typical work requests were selected for review. An attempt was made to include a cross-section of typical work for the activity. The current backlog was not large enough to supply the number of work requests needed, so some recently completed work requests were also used. In the case of the completed work, the estimated cost rather than the completed cost figures were used. The Public Works Officer agreed to act as evaluator for the experiment.

The twenty-five work requests were listed in random order and described for future reference on the identification sheet (Table III). The evaluator then arranged these work requests in order of desirability by intuitive process, attempting to pick the order which would result in the maximum military worth per dollar expended. Local concern for any activity "pet projects" was to be ignored.

After the work requests had been arranged in intuitive preference order, the ranking order was noted in the last column of the identification sheet (Table III) for future comparison with the eventual calculated order. The work requests were then replaced into their original random order and the evaluator was asked to assign numerical grades for each of the five qualitative and qualitative factors as described by Tables I and II. The results of his grading decisions were placed in columns 2, 3, 5, 6 and 7 of the data sheet, as shown in Table IV.

For each work request, the two qualitative factor grades were added, with their sum appearing in column 4 of the data sheet. For each work request, the three quantitative factors were added, the sum appearing in column 8 of the data sheet. For each work request the sum appearing in column 4 and column 8 of the data sheet were multiplied together, the result appearing in column 9. The figure in column 9 was then divided by the estimated work request cost in hundreds of dollars and the result placed in column 10. The calculated ranking order was then determined, with the work request having the largest number in column 10 placed as first priority, and the work request with the smallest number in column 10 placed as the last priority and least desirable of the list. The conceptual background for these calculations appears in chapter IV of the body of this Research Paper. The five factors and the descriptive comments used as a guide in their evaluation are shown in Tables I and II. These factors were determined by intuitive analysis and are not based on other experimental analysis or data.

The calculated preference order was then noted in column 11 of the data sheet for comparison with the original intuitive order shown in the last column of the identification sheet. After reviewing the preliminary results, the evaluator decided to review his factor evaluations, particularly with respect to the absolute savings column of the quantitative factors. A new data sheet was prepared showing all sums and the changed factor scores (Table V). The preference calculations were re-calculated in the same manner as described previously and the second calculated preference order was shown in column 11 of Table V. A graph was made plotting the original intuitive preference order of each work request against its calculated preference order (Figure 1.).

The work requests were then laid out on a table in order of the final calculated preference order, and the results of the experiment discussed.

<u>Discussion</u>. A review of the first results indicated that there may have been some misunderstanding as to the definition and meaning of the quantitative cost factor. Scores for this factor were to have been based on absolute values of cost savings, rather than in comparison with the cost of the project. Some of the factor grades were subsequently revised on the data sheet of Table V, leading to a revised preference order. This second order is considered the result of this experiment, and shall be the only order discussed here.

Figure 1 shows that there was very little, if any, correlation between the first intuitive preference order and the final calculated

order. This means that either the system used was ineffective or that the intuitive order was questionable.

In the review of the calculated preference order, the evaluator stated that there were only two projects that he desired to shift by a significant amount. He felt that work request 5017 (ID# 16) which was tenth in the calculated preference order should be placed twentieth or lower. After discussion it appeared that the real problem here was one of deficiency validity. The activity administration apparently considered the deficiency a valid one, although the evaluator disagreed. Given the basic assumption that the deficiency was valid, its low cost would tend to place the job in the top half of the list. The quantitative mission factor is relatively high since all men entering the enlisted mess would enter through the proposed door.

The other project for which it was felt a shift should be made was work request number 3667 (ID# 2) for installation of transformers. The evaluator felt that the job should be placed significantly higher than the twenty-second priority calculated for it. On questioning, however, it was determined that: (1) the power deficiency for the area involved was not critical, (2) the job had been proposed for some time, but had never started since personnel were needed for more critical projects, and (3) the cost is very high in comparison with the other projects in the sample.

The over-all comments on the calculated preference order were that the list seemed to have the most critical repair jobs towards the

top, followed next by less critical jobs of an appearance nature, such as painting, etc., then followed by alteration and improvement work of lesser importance from a maintenance point of view. The evaluator felt that the approach taken was a rational one, and that, with the two questionable exceptions mentioned above, the list generated was very workable. The calculated preference order was thought to be just as good as the original list, if not better. The evaluator was very interested in the technique and results of the experiment, although the size of his organization and workload is so small that a formal decision system may be of little real assistance.

TABLE I

QUALITATIVE FACTORS

RANGE	MISSION ESSENTIALITY	OPPORTUNITY COST SAVINGS
1-20	Contributes little or nothing to ability of station to meet its mission requirements. Not necessary for support elements. Desirable to maintain or improve aesthetic or appearance.	Project will interfere with normal maintenance. Cost of project will not be returned by future savings.
21-40	Helpful in meeting operational requirements. Desirable to enable supporting elements to meet operational needs. Important to morale and maintenance of appearance of activity.	Project will eventually realize return of the investment involved. Necessary to prevent a needed repair from degenerating to one of larger scope.
41-60	Desirable for easing of operational problems. Important to support elements to help meet operational requirements. Important to morale of base personnel and appearance of activity.	Project would realize significant savings in the first year after completion. Would avoid major change in maintenance or repair scope by present accomplishment.
61-80	Important to fulfillment of operational needs. Drastic substitutes needed otherwise. Essential to proper support of operational needs. A most critical morale or appearance requirement.	Project would save up to twice its cost within the first year after completion. Necessary to avoid large repair work which would otherwise be required.
81-100	Directly and completely applicable to essential operational needs of the activity. Critical to enable supporting elements to meet requirements of necessary operations.	Project would save more than twice its cost within the first year after completion. Necessary to avoid complete replacement of the facility or grossly excessive repair which would otherwise develop.

TABLE II

QUANTITATIVE FACTORS

RANGE	.1-.2	.3.-.4	.5-.6	.7-.8	.9-1.0
TRAIT: MISSION	Project or deficiency affects a minor portion of facilities, functions or personnel	Project or deficiency affects a significant portion of facilities, functions, or personnel	Project or deficiency affects a large part of activity's mission functions	Project affects most of activity mission functions	Project affects nearly all of activity's mission functions
SAVINGS (ABSOLUTE VALUE)	Little or no savings involved	Minor or less than average savings to be expected	Average savings expected	Large or greater than average savings to be expected	Very large savings likely within first couple of years after completion
URGENCY	Project may be postponed up to 12 months with no major lessening of benefits	Project may be postponed up to 6 months with no major lessening of benefits	Project may be postponed up to 3 months with no major lessening of benefits	Important to do project as soon as possible to improve operations or avoid large alternative costs	Immediate need for critical operational needs or to avoid excessive immediate alternative costs.

TABLE III
IDENTIFICATION SHEET (Experiment #1)

ID#	W.O.#	Description	$ Cost	Intuit. Order
1.	4007	Minor repair & paint rear bldg 1	419	7
2.	3667	Install transformers boiler room bldg 6	3808	4
3.	4079	Lay insulation in overhead bldg 1	1010	23
4.	4060	Replace wooden steps w/concrete, bldg. 1	199	17
5.	4008	Curb & Gutter N. side bldg 53	606	9
6.	5024	Repairs to asphalt A/C parking apron	1505	25
7.	3716	Install fluorescent fixtures, hangar 101	1454	10
8.	3989	Repaint trim, windows & doors, hangar 101	701	12
9.	3964	Re-install exhaust system in welding shop	157	3
10.	5031	Remove wall, renovate hopper room	278	20
11.	5034	Rehab. I & E lecture room, bldg. 15	1496	15
12.	5030	Install fluorescent fixtures bldg. 37	222	16
13.	4031	Patch/repaint interior hobby shop garage	480	11
14.	4100	Paint overhead, galley dining room	160	18
15.	5015	Install safety valve piping through roof	275	6
16.	5017	Install door at West side of mess hall	119	21
17.	5018	Misc. repair/repaint, galley kitchen	837	5
18.	5022	Maint. to hangar 6	610	8
19.	5028	Maint. to street signs and markings	355	13
20.	5038	Install wall paper in galley dining room	341	19
21.	5039	Portable partitions for galley entrance	465	22
22.	5040	Replace EM parking area headers	145	24
23.	5041	Maint. to fences, parking lots & signs	230	14
24.	5042	Repair ceramic tile, galley butcher shop	374	1
25.	5044	Repair floor behind Acey-Ducey bar	107	2

TABLE IV
DATA SHEET (Experiment #1 - preliminary)

	QUALITATIVE			QUANTITATIVE						
1	2	3	4	5	6	7	8	9	10	11
#	Miss.	Savng.	Sum	Miss.	Savng.	Urg.	Sum	Prod.	Prod/Cost	Order
1.	30	25	55	.3	.5	.4	1.2	66.0	15.8	7
2.	55	25	80	.6	.6	.2	1.4	112.0	2.9	22
3.	10	25	35	.1	.3	.1	.5	17.5	1.7	25
4.	25	35	60	.1	.6	.4	1.1	66.0	33.2	4
5.	45	20	65	.2	.2	.2	.6	39.0	6.4	16
6.	15	15	30	.5	.3	.1	.9	27.0	1.8	24
7.	45	55	100	.5	.6	.2	1.3	130.0	8.9	10
8.	15	25	40	.3	.3	.3	.9	36.0	5.1	19
9.	45	15	60	.4	.2	.6	1.2	72.0	45.9	2
10.	25	15	40	.2	.2	.2	.6	24.0	8.6	12
11.	45	25	70	.4	.3	.2	.9	63.0	4.2	21
12.	25	25	50	.6	.4	.2	1.2	60.0	27.1	6
13.	30	25	55	.3	.3	.3	.9	49.5	10.3	8
14.	35	25	60	.4	.2	.2	.8	48.0	30.0	5
15.	25	15	40	.4	.1	.1	.6	24.0	8.7	11
16.	10	10	20	.4	.1	.1	.6	12.0	10.1	9
17.	35	25	60	.2	.2	.4	.8	48.0	5.7	18
18.	30	25	55	.3	.2	.3	.8	44.0	7.2	14
19.	20	25	45	.2	.1	.1	.4	18.0	5.1	20
20.	35	15	50	.2	.1	.1	.4	20.0	5.9	17
21.	25	5	30	.1	.1	.1	.3	9.0	1.9	23
22.	15	25	40	.1	.1	.1	.3	12.0	8.3	13
23.	20	21	41	.1	.2	.1	.4	16.4	7.1	15
24.	40	40	80	.2	.7	.7	1.6	128.0	34.2	3
25.	35	40	75	.2	.7	.6	1.5	112.5	105.0	1

[illegible]

TABLE V

DATA SHEET (Experiment #1 - Revised)

	QUALITATIVE			QUANTITATIVE						
1	2	3	4	5	6	7	8	9	10	11
#	Miss.	Savng.	Sum	Miss.	Savng.	Urg.	Sum	Prod.	Prod/Cost	Order
1.			55	.3	.3	.4	1.0	55	13.1	7
2.			80	.6	.4	.2	1.2	96	2.5	22
3.			35				.5	17.5	1.7	24
4.			60	.1	.4	.4	.9	54	27.1	6
5.			65	.2	.1	.2	.5	32.5	5.4	17
6.			30	.5	.1	.1	.7	21	1.4	25
7.			100	.5	.8	.2	1.5	150	10.3	8
8.			40				.9	36	5.1	19
9.			60	.4	.1	.6	1.1	66	42.0	2
10.			40	.2	.1	.2	.5	20	7.2	15
11.			70				.9	63	4.2	21
12.			50	.6	.5	.2	1.3	65	29.3	5
13.			55				.9	49.5	10.3	9
14.			60				.8	48	30.0	4
15.			40				.6	24	8.7	12
16.			20				.6	12	10.1	10
17.	35	35	70	.2	.6	.4	1.2	84	10.1	11
18.			55				.8	44	7.2	14
19.			45				.4	18	5.1	20
20.			50				.4	20	5.9	16
21.			30				.3	9	1.9	23
22.			40				.3	12	8.3	13
23.			41	.1	.1	.1	.3	12.3	5.4	18
24.			80				1.6	128	34.2	3
25.			75				1.5	112.5	105.0	1

[illegible]

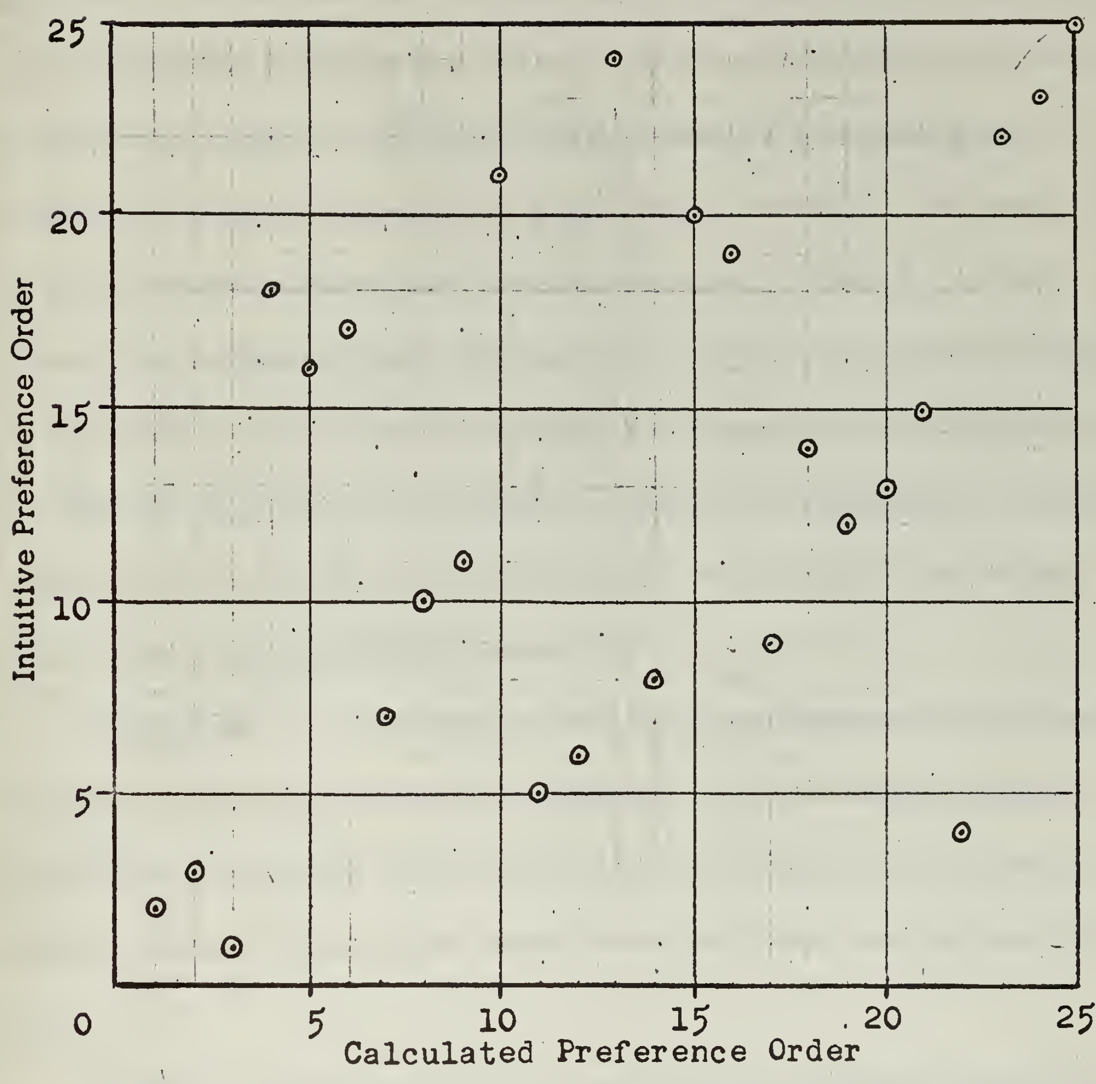

FIGURE 1

PLOT OF CALCULATED PREFERENCE ORDER AGAINST INTUITIVE PREFERENCE ORDER (EXPERIMENT #1)

IV. EXPERIMENT NO. 2

Date of Experiment. 21-22 April, 1964

Location. U. S. Naval Postgraduate School, Monterey, California

Procedure. The procedure used in experiment no. 2 was identical with that of experiment no. 1 except that the graded factor evaluations were not revised after the first results. Only one calculated preference order was developed. The identification sheet for this experiment is table VI. The data sheet for this experiment is table VII. The graph of original intuitive order against calculated order is figure 2. In this experiment the Public Works Officer did not perform as evaluator although he had been consulted prior to carrying the experiment out. He designated his Director of Maintenance Control to perform the experiment. This individual is the one, within this organization, who normally makes the basic priority and scheduling decisions.

Discussion. Figure 2 shows that the calculated preference order for the second experiment has more correlation with the original intuitive order than was the case with the first experiment. Comments of the experimenter, however, were not as constructive, although they are worthy of note.

Again there were two jobs that were said to need adjustment from the preference order calculated for them. The first of these was work request 2871, (ID# 25) for work in a chemistry laboratory at an estimated cost of $525. It was stated that the Public Works Department would be administratively directed to do this work prior to the time it would be

accomplished at the 14th priority level. In view of this fact the evaluation grade for urgency (column 7) should have been higher than .3, and, if the requirement were a valid one, the costs of renting or leasing the required laboratory facilities if the work were not accomplished (absolute cost savings - column 6) should also have been scored higher than .3. Assignment of .7 evaluations to both of these factors would only bring the project from 14th to 9th, however, due to the medium cost of the project.

The other job requiring adjustment was work request 2858 (ID# 19), a large miscellaneous repair project. It was felt that this job should be moved up the list a significant amount, as a very worthwhile project. It is interesting to compare this job with work request 2859, a much smaller job of the same nature in the same building. The smaller job had a 20% higher qualitative savings score than the large one, but a quantitative savings score of more than double the large one. This result is an apparent error on the part of the evaluator. It should be noted, however, that assignment of maximum value of 1.0 to the quantitative savings factor (column 6) would only result in placing the job in twentieth position vice the current twenty-second position.

It was noted that project costs varied from a minimum of \$120 to a maximum of \$4407 - 36 times the minimum cost project. If a minimum value of .1 is assigned to each quantitative factor, the possible range of the quantitative factors sum will be from .3 to 3.0 - 10 times the smallest score. The actual range of the quantitative sums was from a

minimum of .3 to a maximum of 2.1 - 7 times the minimum score. Although the largest project had more than 36 times the cost of the smallest, quantitative factors could only have varied by a factor of 10, and actually did vary only by a factor of 7. As the system is now constituted it would be very difficult to place an expensive project near the top of the list, regardless of its true value in relation to the others. A modification is needed for the quantitative scale to at least provide for the same military worth range as the range of costs for the projects being considered. This might be done by utilizing open-ended quantitative scales which would have no upper value ceiling. Average values could be indicated for projects of normal scope, but provision for large variations from the norm could be made. A detailed study should be able to combat this problem in some manner that would not increase the complexity of the method.

The evaluator started to comment that work request 2833 (ID# 15), new electrical service for the picnic grounds, should be moved up from the calculated order position (ninth) due to the need to straighten out the present "jury rig" power service. It was then noted, that the original intuitive list had shown the project 16th, and the project priority had already been raised from that position by the calculations.

Another comment was that work request 2841 (ID# 10) shouldn't be placed as high on the list as was calculated (sixth). During another portion of the discussion, however, it had been pointed out that this project to replace natural gas service was not an operational need, but

a safety hazard which could potentially involve a major part of a large facility. It would be inappropriate to lower this priority figure unless the hazard is of a minor nature.

TABLE VI
IDENTIFICATION SHEET (Experiment #2)

I.D.#	W.O.#	Description	$ Cost	Intuit. Order
1.	2598	Attic lights, crawl beds, bldg 301	446	24
2.	2657	Furred overhead & lighting bldg 229	1136	11
3.	2675	Exhaust fan in disbursing office	272	18
4.	2680	Maintenance to steam manholes	192	1
5.	2753	Replace tile various rooms bldg 232	121	15
6.	2758	Partitions room 105, bldg 232	642	13
7.	2769	Maintenance to bldg 232	650	5
8.	2784	North & East banks erosion control	477	12
9.	2797	Repair wall in hall 094, bldg 220A	196	22
10.	2799	Maintenance to bldg 234	329	6
11.	2800	3 test lead racks, bldg 232	125	2
12.	2807	4 signs for La Mesa Village	300	10
13.	2874	Rehab. bathroom, room 311, bldg 322	500	4
14.	2828	Remove meat tracks, bldg 220	326	23
15.	2833	New electrical service, picnic grnds.	248	16
16.	2841	Repipe natural gas service, Aerolab	277	14
17.	2848	Repaint rooms, 406, 309, bldg 221	232	19
18.	2857	Maintenance to bldg 322	783	8
19.	2858	Maintenance to bldg 322	4407	9
20.	2859	Maintenance to bldg 322	168	7
21.	7366	Subterranean drainage, 122 Morrell	440	17
22.	2827	Maintenance to bldgs 213 thru 217	225	21
23.	7502	Relocate slide rear of J-115	120	25
24.	7504	Maintenance to J bldgs	338	20
25.	2871	Tables, sink, water, etc., chem. lab.	525	3

TABLE VII

DATA SHEET (Experiment #2)

	QUALITATIVE			QUANTITATIVE						
1	2	3	4	5	6	7	8	9	10	11
#	Miss.	Savng.	Sum	Miss.	Savng.	Urg.	Sum	Prod.	Prod/Cost	Order
1.	5	7	12	.1	.2	.1	.4	4.8	1.1	25
2.	40	25	65	.2	.2	.2	.6	39.0	3.4	21
3.	28	18	46	.2	.2	.1	.5	23.0	8.5	15
4.	90	60	150	.8	.7	.6	2.1	315.0	164.0	1
5.	18	25	43	.2	.2	.2	.6	25.8	21.3	7
6.	30	22	52	.1	.1	.5	.7	36.4	5.7	18
7.	65	24	89	.4	.5	.6	1.5	133.5	20.6	8
8.	10	44	54	.1	.7	.5	1.3	70.2	14.7	10
9.	5	21	26	.1	.1	.2	.4	10.4	5.3	19
10.	63	22	85	.2	.5	.5	1.2	102.0	31.0	5
11.	45	25	70	.1	.2	.4	.7	49.0	39.2	4
12.	45	15	60	.4	.1	.1	.6	36.0	12.0	12
13.	40	50	90	.1	.8	.7	1.6	144.0	72.0	3
14.	10	5	15	.2	.2	.1	.5	7.5	2.3	24
15.	5	30	35	.2	.7	.2	1.1	38.5	15.5	9
16.	21	26	47	.3	.5	.6	1.4	70.5	25.5	6
17.	15	5	20	.1	.1	.2	.4	8.0	3.5	20
18.	60	30	90	.2	.5	.4	1.1	99.0	12.7	11
19.	60	50	110	.2	.4	.7	1.3	143.0	3.3	22
20.	60	60	120	.2	.9	.7	1.8	216.0	128.5	2
21.	30	20	50	.1	.2	.3	.6	30.0	6.8	17
22.	20	15	35	.2	.1	.2	.5	17.5	7.8	16
23.	5	5	10	.1	.1	.1	.3	3.0	2.5	23
24.	22	25	47	.2	.4	.1	.7	32.9	9.7	13
25.	46	22	68	.1	.3	.3	.7	47.6	9.1	14

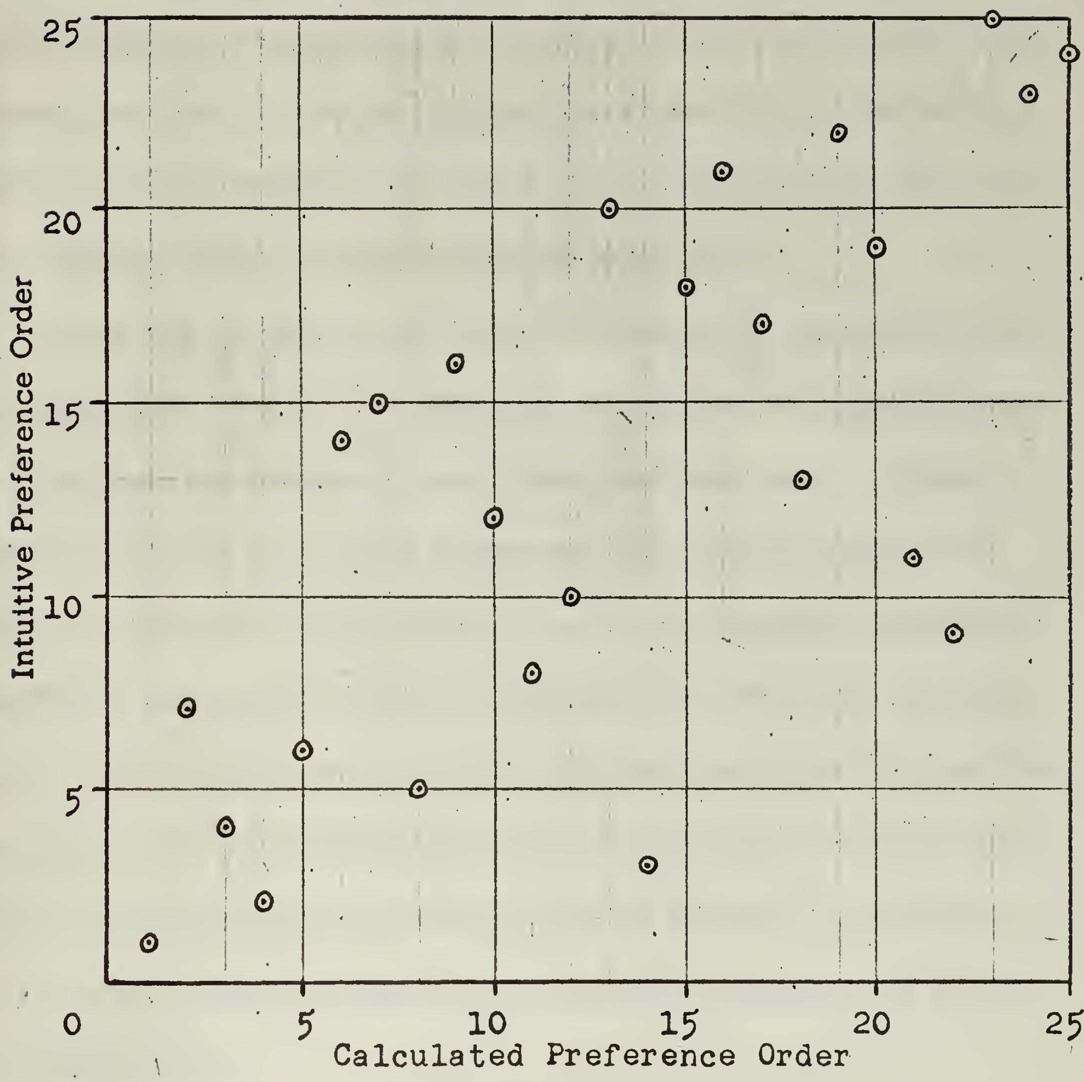

FIGURE 2

PLOT OF CALCULATED PREFERENCE ORDER AGAINST INTUITIVE PREFERENCE ORDER (EXPERIMENT #2)

V. CONCLUSIONS: BOTH EXPERIMENTS

The experiments did not, in fact, clearly determine whether or not the military worth system proposed here was the proper system for establishing workload priority. The calculated preference order in both cases correlated very poorly with the preference order established by intuitive means. This fact alone, however, does not tell one that the system is no good. There is considerable evidence that the intuitive method may have developed several failings in determining the order in which maximum worth would be returned to the Navy.

There was no strong opposition to either of the calculated priority lists developed, even though such poor correlation developed between the calculated and intuitive lists. This would lead one to wonder if, with the exception of projects at the very high and low ends of the scale, intuitive means of decision in such a problem are incapable of determining the relative merits of projects in the mid-range of desirability. Perhaps local pressures play a greater part in decision-making than logical and rational analysis based on the over-all goals of the Navy. Intuitive decisions on the transformer project in experiment 1, and the picnic ground and natural gas service of experiment 2 are at least questionable.

It has already been noted in the discussion of experiment no. 2 that the present scale structure does not provide opportunity of adequately considering the possible benefits of projects with very large scope. The sum of quantitative factors would not usually vary by more than a factor

of 10, while the magnitude of scope measured in cost figures varies in both instances by factors greater than 30. In both cases, one of the two projects whose calculated ranking was considered incorrect involved jobs of very high cost which had been ranked near the bottom of the preference scale. It is recommended that future studies of a similar nature be structured so as to be able to give large projects proper cost effectiveness factor ratings when they are deserved. A future experimenter would be cautioned, however, not to go to extremes in obtaining benefits for large jobs. The larger projects are exactly the ones which should receive the greatest test for military worth, simply due to the fact that a major investment is involved. They should be made to prove their value in competition with smaller projects. It should not be possible, however, to improve a large job's ranking merely by substituting for it two projects of half the scope, such as might be the case under the present system.

It should also be noted that any system of this nature which tends to "impersonalize" priority determination will be useless if the command attitude at the activity is not receptive to the idea. It must also be recognized that a Commanding Officer, for various reasons, will feel that he must occasionally contravene such a system in carrying out his responsibilities. This does not say the system is not worthwhile. If the system does nothing more than assign relative desirability to standard work requests, being modified for particular non-standard reasons, it will have performed a fine "management-by-exception" function. It

is certainly not suggested here to do away with higher-level review of workload assignment just because of a new "scientific" system.

A system such as this should be helpful in structuring the decision thought process. When there are problems in determing which of two jobs are more important, a look at the factor scoring sheet will help indicate _why_ one job should be preferred over another. The system has the effect of putting the thought process on paper for all to observe. The reasons for a decision are more obvious and subject to more rational analysis. This feature of the system was frequently observed when discussing why one project varied greatly in preference order from its original intuitive position.

The comment must be made that there is no known objective way of measuring the results of this experiment. This would involve measuring the value of the intuitive system against the value of the system of calculations and evaluations. If such a measurement system is available, then this project should be abandoned and the measurement device used to determine whether the Navy is doing the right maintenance job or not. The only means of evaluating such an experiment at the present time is through a subjective analysis of the results by experienced maintenance personnel with the results of the analysis expressed as professional opinion. Both evaluators in the experiments expressed interest in the system as used, and confidence in the basic logic through which the system was developed. The author also feels that the concept is logically sound and that detailed work in this area could arrive at the

structure of a similar system which would be easily applied at the local level. These are the "professional" opinions obtained in this case. Opinions by those with superior background would be desirable.